ADDENDUM
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Large Acceptance Hadron Detector for an Investigation of Pb-induced Reactions at the CERN SPS

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1. Motivation for a revised P264 layout

One of the principal concerns of the SPSLC Committee and of our referee about our proposal for a Large Acceptance Hadron Detector can be summarized as follows:

"Once you propose such a high effort to identify a variety of hadrons in as wide an acceptance as possible: does the suggested layout really represent the optimum configuration and, furthermore, have you made compromises that severely limit a fully comprehensive hadron analysis, in order to keep the total cost at a tolerable level?"

This addendum describes a revised layout that results from carefull consideration of these two critical aspects. It also addresses briefly several other questions and concerns raised by the CERN committee.

Fig. 1 shows the "old" layout given in the original proposal (fig. 6 there). We recall the basic ideas of this layout:

1. We concentrate on charged hadron identification above mid-rapidity, i.e. at $y \geq y_{mid} = 2.9$. The main part of the identification task can then be carried out by a large volume, modular TPC (Main TPC) which accomplishes the tracking (for particle momentum) and also provides for hadron identification by precision measurement of the ionization in the domain of the relativistic rise. This concerns π^{+-}, K^{+-}, p and $\bar{p}$.

2. For analysis of the Λ and $\bar{\Lambda}$ production at $y > 2.9$ and at low transverse momenta we add a further Vertex magnet. The first, VM1, serves as a "sweeper" that reduces the track density in the fiducial volume of the second dipole, VM2, to a degree that V^o reconstruction of neutral strange particles can be carried out in a Vertex TPC, positioned in VM2. This is the only way (in view of the high charged hadron multiplicity) to cover the low-to intermediate-transverse momentum domain of Λ, $\bar{\Lambda}$ with a reasonable

3. Mid-rapidity π^{+-} and K^{+-} fall below the domain of Lab momenta in which identification by ionization can be performed (see fig. 10 of proposal). We thus add an array of time of flight (TOF) detectors that work in conjunction with the TPC (see fig. 13 of proposal).

4. The overall trigger on approximately central collisions is derived from two calorimeters that determine the forward energy flow and the transverse energy. The resulting "central" trigger sample is then inspected <u>event by event</u> in the tracking detector analysis off-line, leading to sub-ensembles according to certain event properties of specific interest.

The features of the above layout that call for a critique and require improvement are chiefly the imperfect coverage of mid-rapidity pions, and the complete omission of π^+ below $y \approx 4$, and K^+ below $y \approx 3.4$, due to the asymmetry of the layout as far as tracking and TOF sideward of the Main TPC is concerned. The latter feature did indeed follow from cost considerations only: the layout of Fig. 1 can clearly be made symmetric by a further Side TPC and TOF.

The most critical feature is the insufficient coverage of low p_T mid-rapidity pions (of either sign), which is caused by the high deflection of $p_{Lab} \approx 1.5$ GeV/c tracks by VM1. Fig. 2 shows the effect of this on the acceptance for pions in y and p_T. At $y_{mid} = 2.9$ all pions are lost below $<p_T> = 0.35$ GeV/c. This impairs severely the analysis of Bose-Einstein two pion correlations at mid-rapidity because about 80% of all relevant (close momentum) pairs contain pions that are at $p_T \leq <p_T>^2 \approx 0.2$ GeV/c! Actually it also might render impossible any reliable event-by-event evaluation of the pion correlation. We thus decided that a tracking detector inside VM1 is required.

Fig. 3 shows the new layout. VM1 contains a TPC that is fairly similar in construction details to the Vertex 2 TPC described in the proposal. The next section will deal with this new detector and the resulting acceptances. We note here that we are considering a staging plane in our instrumentation effort: in the original proposal it was foreseen to equip the Vertex (2) TPC with 24.000 electronic channels. This led to the Λ, $\bar{\Lambda}$, K_s^o acceptances shown in fig. 16, and to the $\bar{\Lambda}$ reconstruction accuracy given in fig. 17 (proposal). We propose, as a first step of staging, to take about half of this electronics away from the Vertex (2) TPC and employ it for the VT (1) TPC. We prefer to do this not by thinning out the sampling density in the VT (2) TPC, but by taking away all electronics from the positive particle side. The track density here is higher anyhow due to the participating protons, such that V^o reconstruction is far less effective than at the negative particle side. The overall Λ, $\bar{\Lambda}$ detection efficiency for low-to intermediate-p_T lambdas results almost entirely from the negative side, anyhow. The form of the Λ, $\bar{\Lambda}$ detection domain given in fig. 17 (proposal) thus remains essentially unchanged. With the 12.000 channels we will equip the negative side of the VT (1) TPC, thus securing a sufficient momentum resolution (see next section) for pion correlation study. The acceptance for negative pions is dramatically improved in this scheme. The additional domain in y, p_T is indicated by the cross-hedged area in Fig. 2. It actually reaches down to $y \approx 2$ with no low p_T hole.

With the remaining restriction to negative hadrons, this first stage of extension (at a very modest cost increase only) removes the concern about the π^- pair correlation analysis event by event, and also the total "blindness" of the proposed experiment to the phase space below mid-rapidity - another critical issue raised by the SPSLC. Note, however, that there is no particle identification in the newly accessible part of phase space, except for electron rejection by ionization which should be possible in this VT (1) TPC configuration.

Of almost equal importance as the improvement of pion observation is the coverage of both K^- and K^+ down to mid-rapidity. The new layout, Fig. 3, thus shows two TOF arrays symmetrically backing the Main TPC at the negative and positive side. Fig. 4 shows the corresponding y - p_T domain of K^{+-} identification by ionization in the Main TPC alone, corresponding to the line at $p_{Lab} = 7$ GeV/c, and the domain covered jointly by the TPC and TOF (the border-line corresponds to 20% acceptance). The gain by TOF in phase space coverage may appear marginal from Fig. 4 but recall that the $p_T < \langle p_T \rangle \approx 0.5$ GeV/c domain is the region of highest significance, both to K^+K^+, K^-K^- interferometry and to the discussion of low p_T spectral shapes. We can now also explore further the possibility of $\Phi \to K^+K^-$ decay observation at mid-rapidity.

The TOF configuration given in Fig. 3 adds about 1 MDM to the total cost of the experiment. It could, thus, be considered the first step of a staged approach. It makes the experiment symmetric in the coverage of K^{+-} down to mid-rapidity, low p_T. The configuration drawn in Fig. 3 refers to opposite field polarity in the two magnets. With parallel fields the dispersion of charged particles is wider (see fig. 9 of proposal). For a variety of tracking-related reasons, we actually prefer the latter configuration. The additional TOF 2 array would now be placed behind the Side TPC (see Fig. 3) to cover midrapidity K^- in a comprehensive way. This configuration stays asymmetric (we will thus employ both polarity choices). Obviously there is room for further staging, the next step being a complete electronic instrumentation of the VT (1) TPC.

In the following sections we will briefly address the details of the VT (1) TPC, of the TOF technique, and of the limitations to correlation analysis due to scanning efficiency, momentum resolution and 2-track separation.

2. New TPC in the first Vertex Magnet

The tentative design features of the tracking TPC in the first Vertex Magnet, VT (1) TPC, are based on the design of the Main TPC and the VT (2) TPC as outlined in our proposal. All these TPC's are modular and can be easily reconfigured. We mention here that they are, thus, also potentially useful to further experiments, and also to staging variations of our present layout that are not foreseen yet. Six prototype modules, with a sensitive area of 77 x 60 cm^2 each, are operating successfully in NA35.

Fig. 5 provides a sketch of the construction, both in a top and in a front view. Due to the high particle density a good 2-track resolution is required beside the continuous track following capability. Furthermore thin walls are needed to reduce photon conversions and secondary interactions. A vacuum beam pipe helps to keep space charges as low as possible. The overall dimensions of the field cage are approx. 2100 mm in beam direction, 1400 mm wide, and 700 mm high.

Electrons drift to the top where an area of 600 x 2100 mm^2 is covered with 3 readout modules on the negative particle side. Provision will be taken that in a later stage also the other side can be equipped with readout chambers. A thin walled, light material vacuum tube with 180 mm diameter contains the beam and a large number of the fast particles, including most of the protons. That way the ionization of the beam and other particles is avoided and the space charge in the drift volume is reduced. Additional drift field correction wires shield the drift volume below the readout area.

The 3 readout chambers are 600 mm wide and 700 mm long in beam direction. Their mechanical design is based on the experience with the NA35-TPC and similar to the Vertex (2) TPC. To obtain the best possible 2-track resolution the chambers have in addition to the 2 mm gap (narrow pad response function) "inclined" or curved pad rows. This gives for most of the tracks "nearly perpendicular" incidence and therefore the optimum in accuracy of the position measurement and 2-track resolution. Pending a detailed MC study we axpect to obtain a momentum resolution of better than $2 \cdot 10^{-3}$ p. Each module has 40 pad rows with 170 pads (3.5×10.5 mm^2) which gives 6800 pads per module and 20.400 pads in total. Of these, we will initially equip 12.000 channels only, employing lower granularity in the regions where the tracks are rather straight. In later stages we will equip all channels, and also the positive side.

The field cage construction is similar to the Vertex (2) TPC. This is also planned for the laser calibration, gas, and readout electronics. For the latter one this is also valid in respect to the Main TPC to have the same electronic parameters for all the TPC's in the experiment. Provided that the 12.000 electronics channels are, at first, taken from the VT (2) TPC, the total additional cost of the VT (1) TPC is about 0.5 MDM.

The acceptances for charged hadrons, and for negative pions in particular, are markedly improved by the addition of the VT (1) TPC. This is illustrated for pions in Figs. 6a, b and c which give contour lines in the y, p_T plane for 10% to 100% nominal π^- acceptance (see below for efficiency corrections etc.) in the Main TPC (a), the Side TPC (b) and the VT (1) TPC (c). The rapidity coverage is extended down to about y = 2. A minimum path length of 50 cm was required in the VT (1) TPC. The average path length of the tracks included in the acceptance plots ($l \geq 50$ cm) is about 110 cm in this TPC, in contrast to all other TPC's where most of the tracks traverse the entire depth of the chamber.

The overall acceptances for negative pions and p, $\bar{p}$ are given in Fig. 7a - c. The full histogram refers to central Pb + Pb collisions at 180 GeV/nucleon as generated by Fritiof. The tracks were then passed through GEANT, establishing cuts according to successively more restrictive criteria: a track leaves at least 50 cm in one TPC, it does not fall into the beam pipe (not illustrated in Fig. 3), it is not perturbed by a second track at an average distance of less than 1 cm, and it can be identified by ionization and TOF. Considering π^- in Fig. 7a one recognizes the darkest shading area as the one which satisfies all cuts. Toward lower rapidity it is augmented by the tracking-only output, mostly from the VT (1) TPC which gives no particle identification. The losses due to high track density, beam pipe, too short tracks in volume etc. amount to about 10% only at mid-rapidity, increasing to about 30% at $y > 5.5$.

Two short comments are in order here: a) the assumption made above that in the event of two close tracks both tracks are lost is certainly a conservative one. We will discuss this in sect. 4, considering Bose Einstein pion correlation, for which two (or more) close tracks are of key importance.
b) To the above detection criteria one would have to add further restrictions, such as a general off-line track reconstruction inefficiency and an uncertainty in the verification that the track originates from the primary interaction vertex.

Overall we will have a detection efficiency of about 90% in the centers of our y-acceptance for each particle species. The protons are most affected by inefficiencies and identification limits at $y \geq 4.6$. However, the importance of this for the intended physics is exaggerated in Fig. 7b because it is known that Fritiof has too little proton stopping. The actual distribution of the participating protons is expected to look rather similar to the pion y distribution. Thus the inefficiency at $y > 5$ will play a tolerable role.

3. TOF Detector Development

Two segmented time-of-flight detector arrays consisting of 700 elements each are proposed for supplementing the particle identification of the Main TPC. Each sub-module will consist of a plastic scintillator with 20 cm^2 sensitive area read out by a 1" photomultiplier through a conical light guide (see fig. 33, proposal). A TOF resolution of $\sigma = 100$ ps (standard deviation) is required for separating Kaons close to mid-rapidity (4 to 7 GeV/c) from pions and protons.

Apparently, the suggestion to use 1" phototubes has raised concern, the argument being that 2" tubes are better suited for fast timing, whereas the electron-optical systems of smaller tubes are usually not optimized for this purpose. The following table compares the relevant properties of fast 1" and 2" tubes according to the manufacturers specification:

Hamamatsu				RT	TT	TTS
R 2076	3/4"	8 stages		1.3 ns	14 ns	0.15 ns
R 1828	2"	12		1.3 ns	28 ns	0.23 ns
R 2083	2"	8		0.7 ns	16 ns	0.16 ns
Philipps						
XP 2972	1 1/8"	10		1.9 ns	23 ns	0.3 ns?
XP 2962	1 1/8"	8		1.8 ns	20 ns	
XP 2020	2"	10	(UR 1)	1.4 ns	24 ns	0.15 ns

RT = rise time, TT = transit time, TTS = transit time spread (standard dev.)

Our conclusion is that 1" tubes with adequate timing properties are available (1" tubes are generally cheaper by a factor of two).

A test program was started a few weeks ago. Various photomultiplier types (XP 2962, XP 2972, R 3478 (= equivalent to R 2076)), scintillation materials (Pilot - U, NE-104) and light guides were and will be investigated. Standard NIM electronics is used, the most critical part being the leading edge discriminator (Philipps Scientific FS 708). The electronics was tuned using ß-particles from a ^{106}Ru source, the final measurement being carried out with cosmic rays. The time spectrum shown in Fig. 8 was obtained with a small scintillator (25 x 25 x 50 mm^3) read out by two XP 2962 photomultipliers without light guides. A window was set on the pulse height in order to select minimum ionizing particles in the cosmic radiation. The time difference between the two multiplier pulses is determined with a standard deviation of 100 ps, giving a resolution of $\sigma = 70$ ps for each multiplier.

Remarks:

a) The measured time spread can be fully explained by the position variation of the cosmic rays in the scintillator. Therefore the real time resolution must be better.

b) It is reasonable to quote the resolution for one tube (measured σ divided by $\sqrt{2}$), because in the real experiment the start signal is derived from a counter in the beam. The highly ionizing beam particles give a much better timing signal than minimum-ionizing reaction products.

We are, thus, confident to reach the TOF specifications for Kaon-pion separation with 1-inch (cheap) photomultipliers.

4. Detection efficiency for Bose-Einstein correlation

We note that we intend to investigate the two- and multiparticle correlations in 4-momentum space for the following cases:

a. Event by event negative hadrons in $2 < y < 4.5$ for "source radius" characterization of each event;

b. Precision analysis in selected event ensembles for 2, 3, 4-negative hadron correlations. Negative pion correlations will supersede the negative hadron data in the identification domain $y \geq 3$;

c. Precision analysis of K^+K^+ and K^-K^- correlation in selected event ensembles.

In a single central event we will record about 10^5 negative hadron pairs, just sufficient to construct a meaningful correlation function in invariant momentum and/or in transverse/longitudinal directions. Particle identification is not essential at this low statistics level. It is useful, however, in ensemble analysis of some 10^4 events (with some 10^9 pairs) for two-pion correlations, and it is indispensible in Kaon correlation and multi-pion correlation analysis.

As this addendum mostly concerns the newly added TPC in the Vertex magnet we note here that its chief advantage thus is in the event by event analysis (which would probably be impossible otherwise), without particle identification other than e^- rejection.

In more detail the various limitations to HBT analysis are illustrated in Fig. 9. For negative pions, it shows the
y - p_T areas

a. with/without particle identification,

b. with "too close tracks" in the sense that two tracks with a Δp_T and/or Δp_L^{cm} of 10 MeV/c or less are closer than 1 cm in the TPC, and

c. with "too hard" tracks, such that the finite momentum reconstruction accuracy forbids a correlation analysis at $\Delta p \rightarrow 0$.

The identification limit appropriate to ionization measurement is given qualitatively by the line $p_{Lab} = 2.5$ GeV/c in Fig. 9. At mid-rapidity, there is thus no PI below $p_T \approx 0.3$ GeV/c (only negative hadron assignment). For negative hadrons this is not as harmful as one might intuitively assume. This stems from the fact that the admixture of K^- and $\bar{p}$ to the π^- yield is not 15% here. There occurs a suppression by a factor of two due to the higher $<p_T>$ of K^- (about 0.5 MeV/c) and $\bar{p}$ (about 0.65 MeV/c). Furthermore, these mid-rapidity pions at $p_{Lab} \approx 2$ GeV/c are contaminated by antiprotons and Kaons located far below mid-rapidity, such that their dN/dy is reduced by another factor of about two, in comparison to the corresponding peak values. We will thus have about 5% K^- and $\bar{p}$ contamination only in this domain of phase space, not warranting particle ID efforts.

The other, most significant limit stems from the two-track separation. We expect to require track pairs at least as low as 10 MeV/c in invariant momentum difference. The most stringent limitation concerns the transverse momentum difference (the Lab to cm Lorentz factor boosts Δp_L^{cm} = 10 MeV/c to $\gamma \cdot$ MeV in the Lab). Fig. 9 shows the line where Δp_T = 10 MeV/c corresponds to less than 1 cm track spacing. A very significant limitation to the domain of HBT analysis appears to result. However, the criterion employed in Fig. 9 may be too restrictive. Why should two tracks at less than 1 cm distance be lost? It is true that the TPC signals of the tracks, both in the pad plane and in the time (z) dimension, will overlap to an increasing degree as $\langle distance \rangle \rightarrow 0$. However, the ionization signal goes to twice the single track value in that case. This was verified by data gathered with the NA35 prototype TPC. Double tracks can thus be recognized in the TPC, and we expect to be able to derive, from the 108 samplings gathered along the tracks, an unfolding for such double tracks, at least down to about 5 mm distance. Further study of this unfolding (also regarding particle ID) is in progress currently.

In summary, we expect to perform HBT analysis in the interval $2 < y < 4.5$ for negative hadrons, and in the interval $2.8 \leq y \leq 4$ for identified negative pions.

APPENDIX

1. 2 mm Readout Chambers

In chapter 3.2.1 of the proposal we discussed a 2 mm gap between the pad plane and the sense/field wire plane to reduce the width of pad response function (PRF). This would improve the two-track resolution.

In the meantime we have modified the test TPC and have made a comparison between 2 and 3 mm gaps. The results are as follows:

(1) The operation of the proposed 2 mm geometry has shown no problems at all.

(2) The measured width of the PRF is $\sigma = 2.0 \pm 0.2$ mm for the 2 mm gap and $\sigma = 2.6 \pm 0.2$ mm for the 3 mm gap.

2. Vacuum Beam Tube

A prototype for a possible vacuum beam tube inside the TPCs was constructed (see pictures) and mechanically tested. It has a length of 1000 mm, 50 mm inner diameter, and a wall thickness of 5 mm. The wall has a sandwich structure consisting out of 5 mm thick Rohacell (lucite foam, 50 mg/cm^3) laminated with 40μm thick Tedlar foil on both sides. The foil gives the gas thightness and has a very low conductivity to avoid electrostatic charges on the surface. The total wall thickness corresponds to 0.17 % of a radiation length for perpendicular incident particles.

The tube was successfully tested with vacuum inside and an additional 1 atm overpressure from outside.

From MC studies we expect two conversions per Pb + Pb collision.

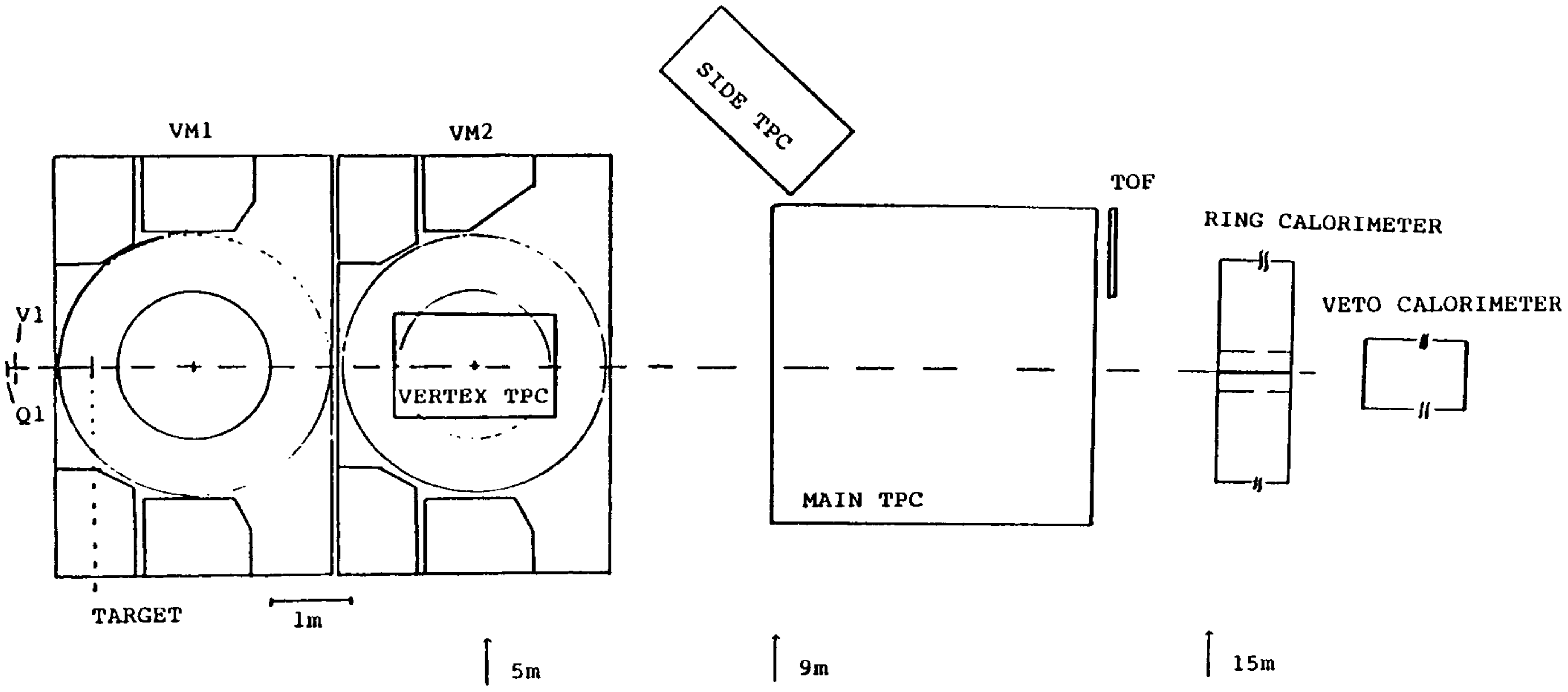


Fig. 1: Large Acceptance Hadron Detector: "old" layout

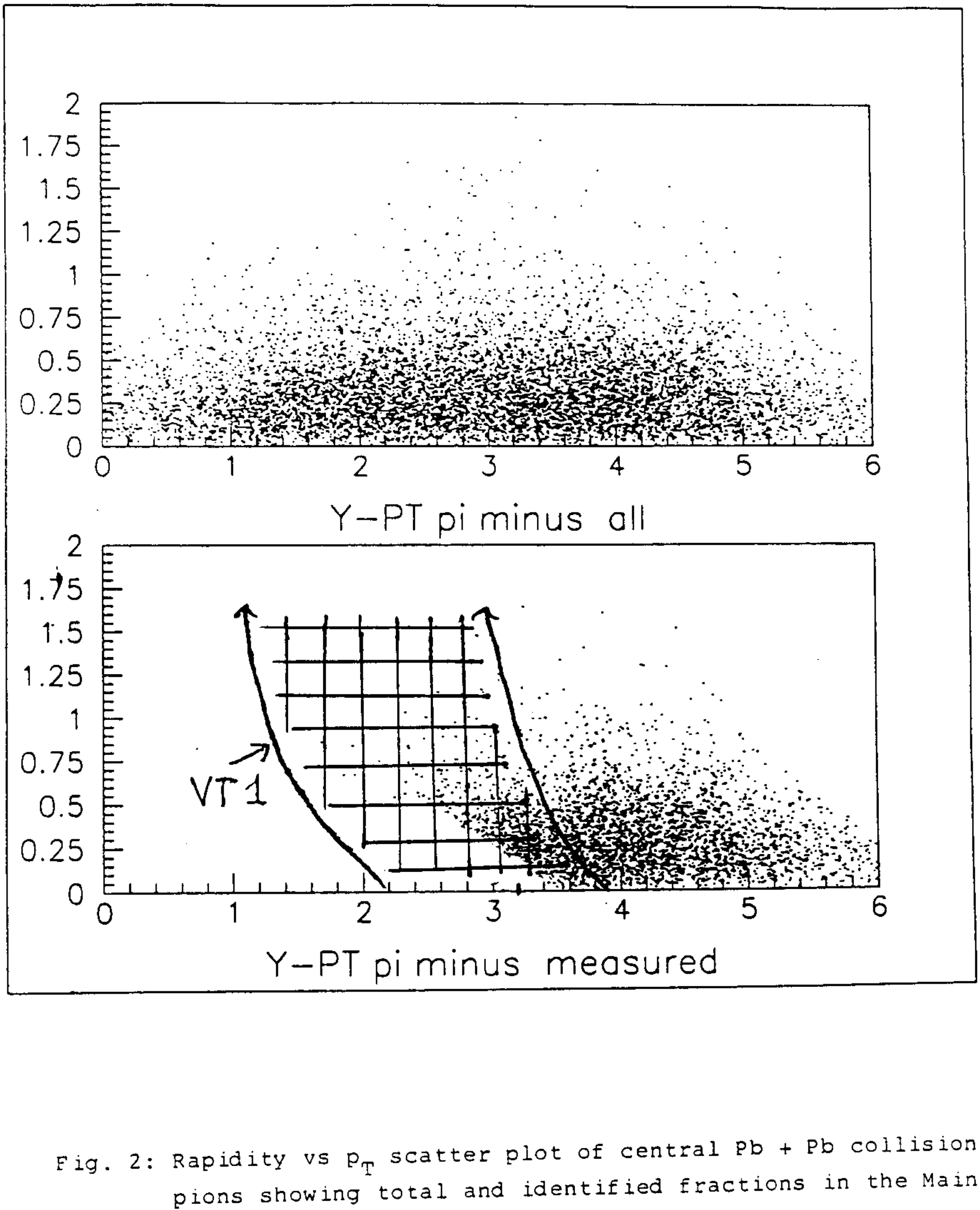


Fig. 2: Rapidity vs p_T scatter plot of central Pb + Pb collision pions showing total and identified fractions in the Main and Side TPC's together. Cross-hedged area indicates the acceptance domain (>50% efficiency) for π^- in the additional VT (1) TPC

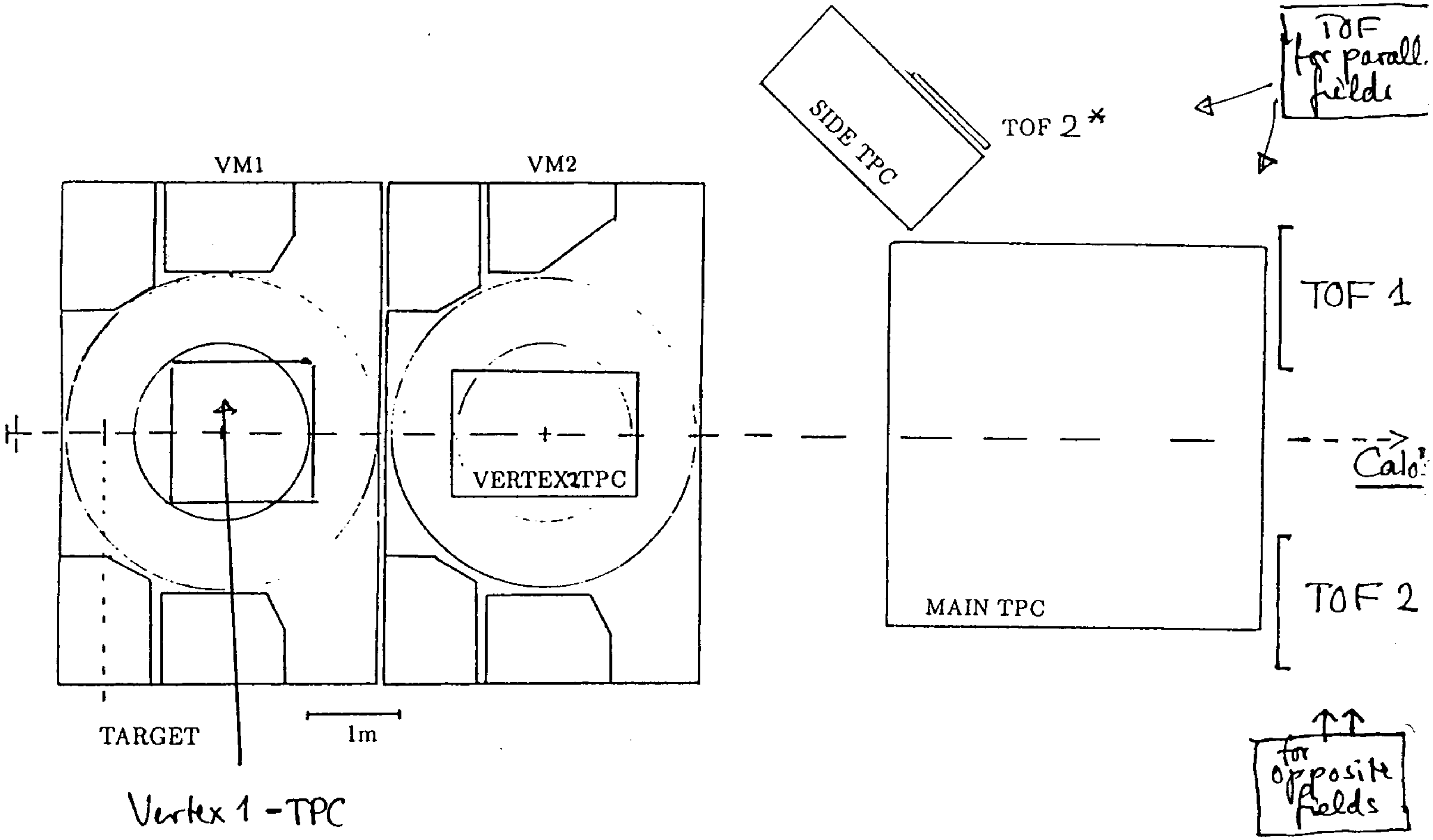


Fig. 3: N[illegible] Large Acceptance Hadron Detector layout

$\boxed{Pb+Pb \rightarrow K^{\pm}}$

Identification: $p_{Lab} \begin{cases} > 7\,GeV/c : TPC \\ < 7\,GeV/c : TOF + TPC \end{cases}$

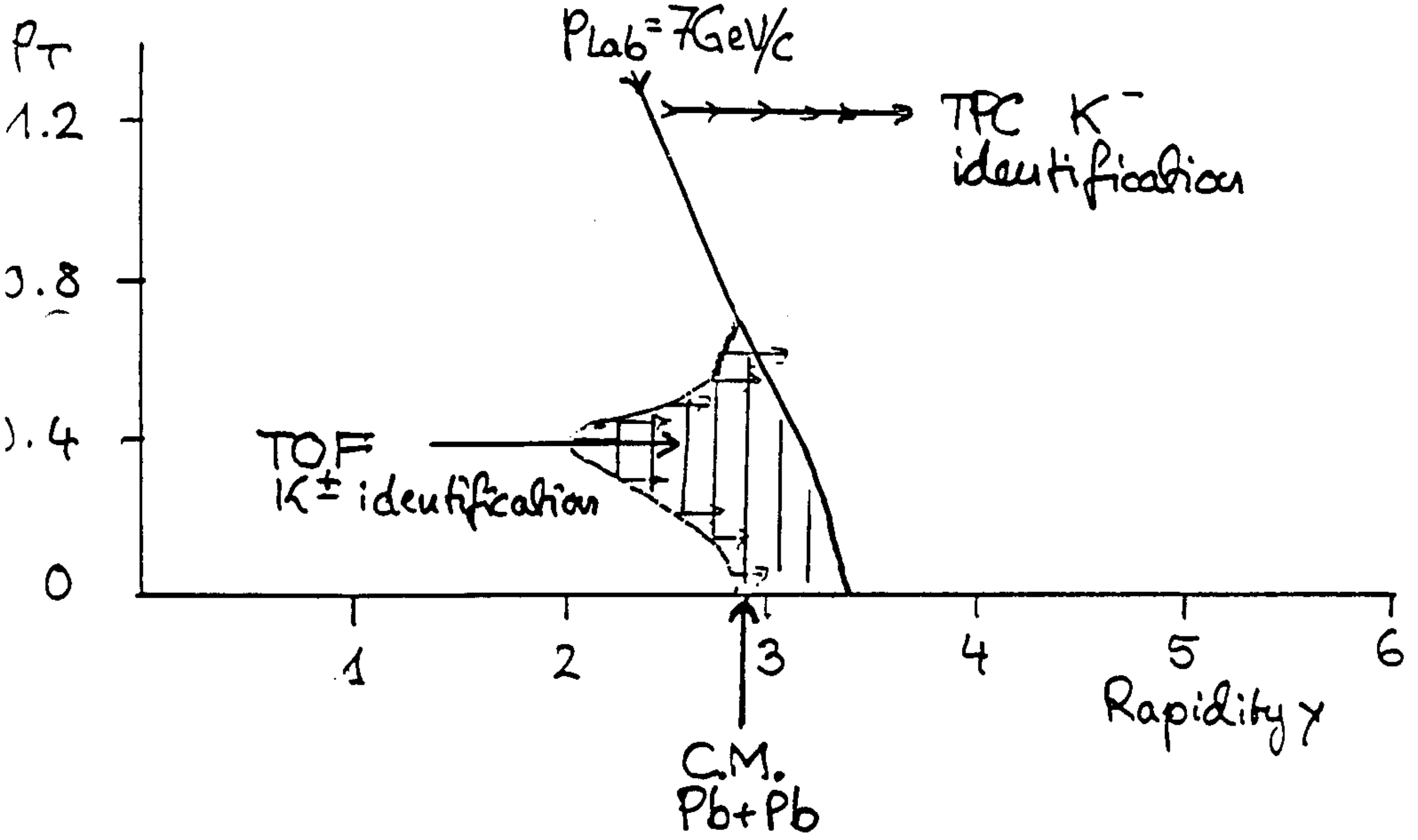
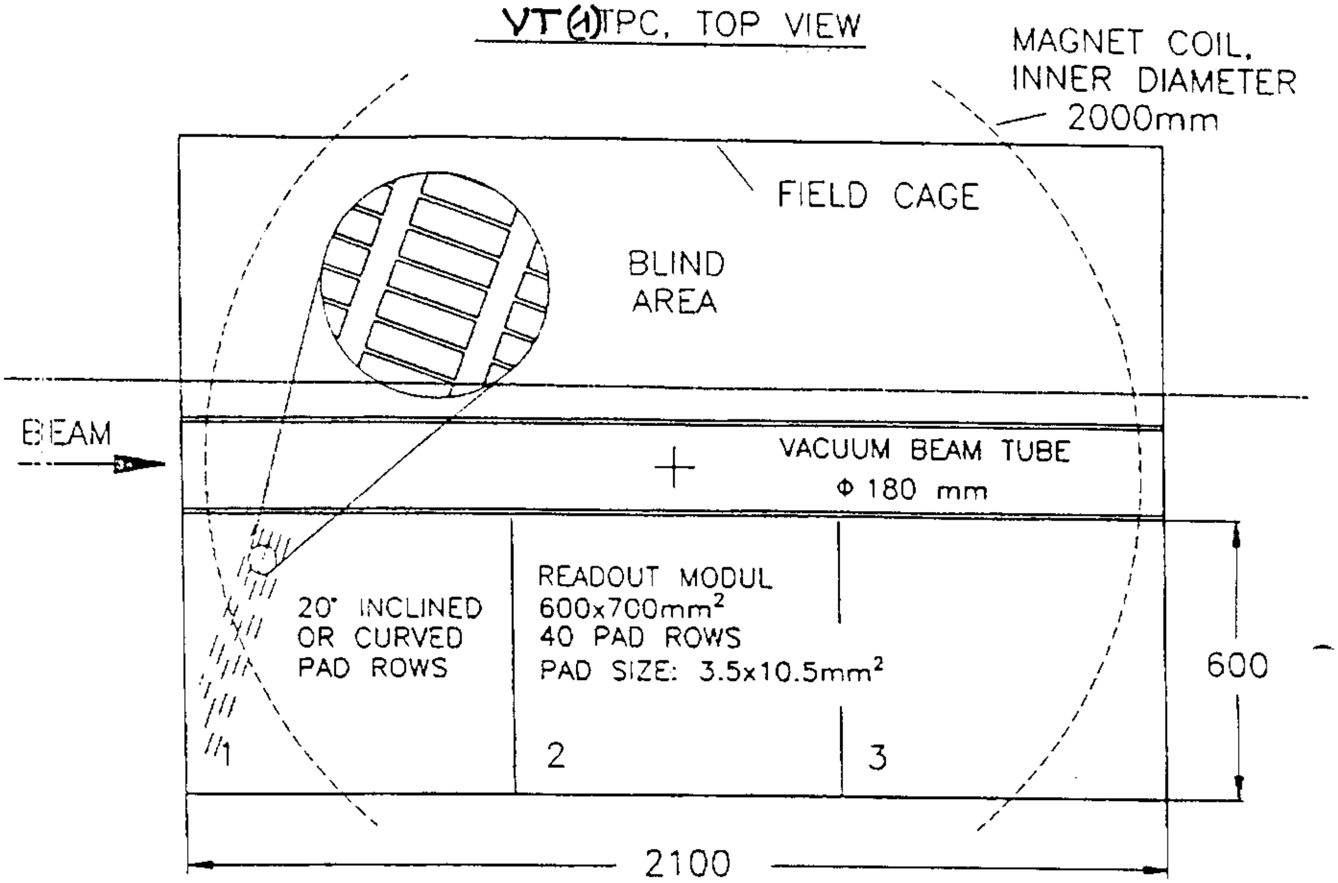
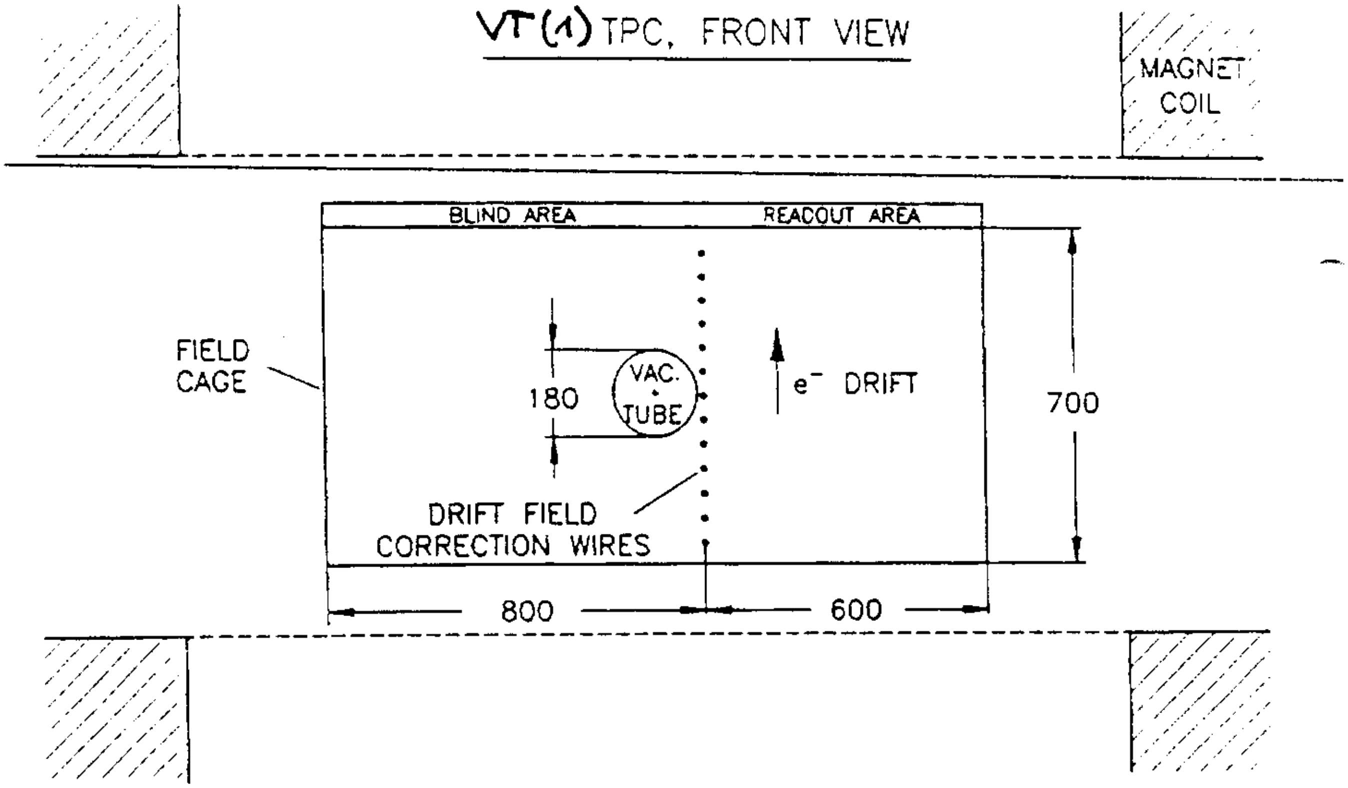


Fig. 4: Kaon identification domains, by ionization (Main TPC) and jointly by ionization and TOF (hedged area)

VT(1) TPC, TOP VIEW



VT(1) TPC, FRONT VIEW



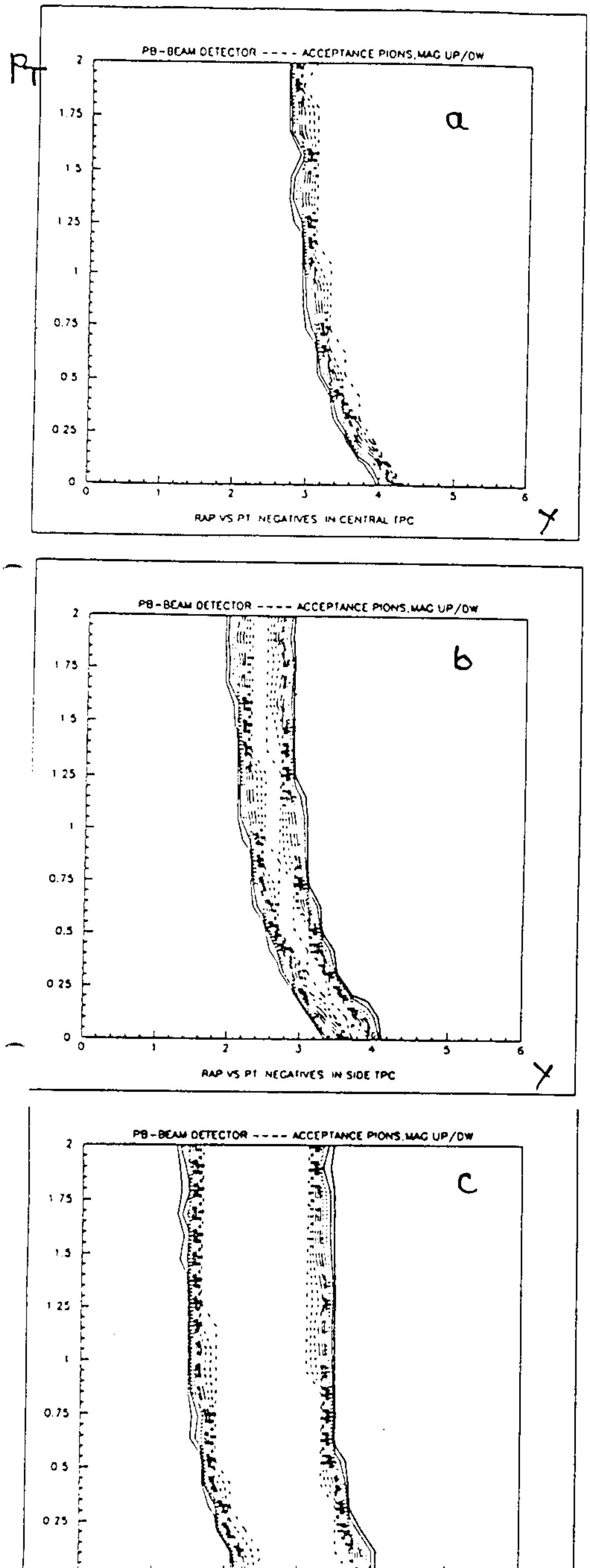
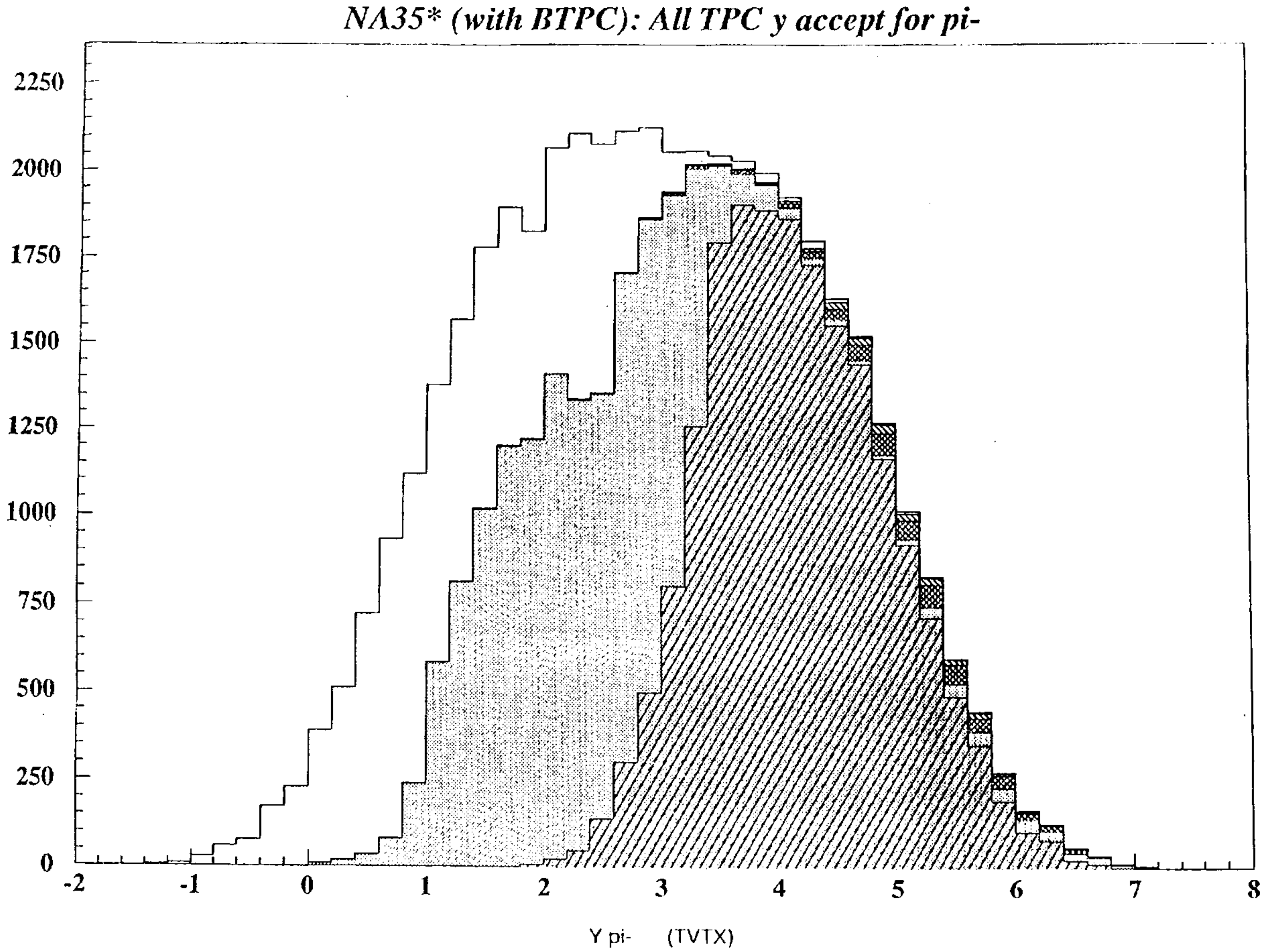
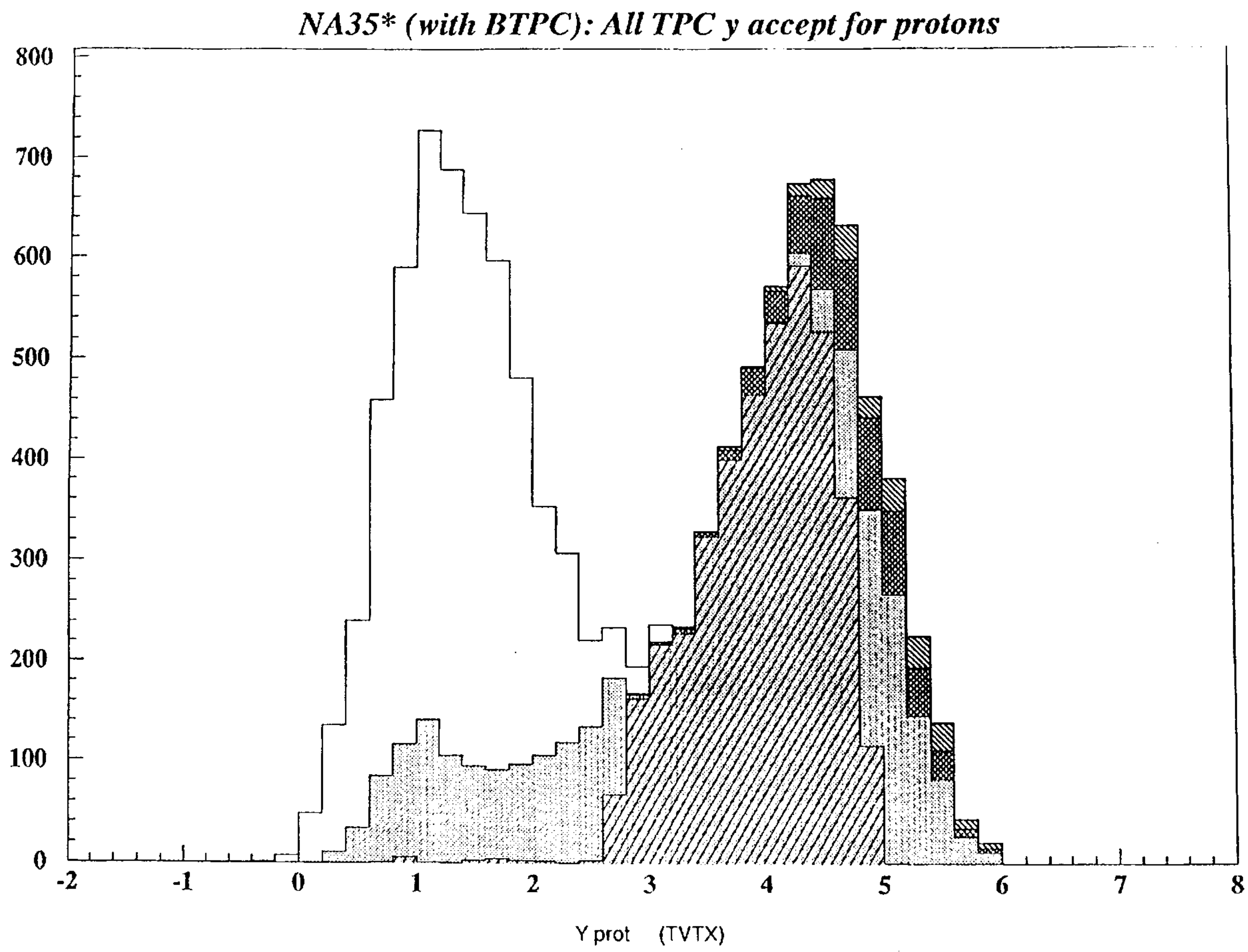
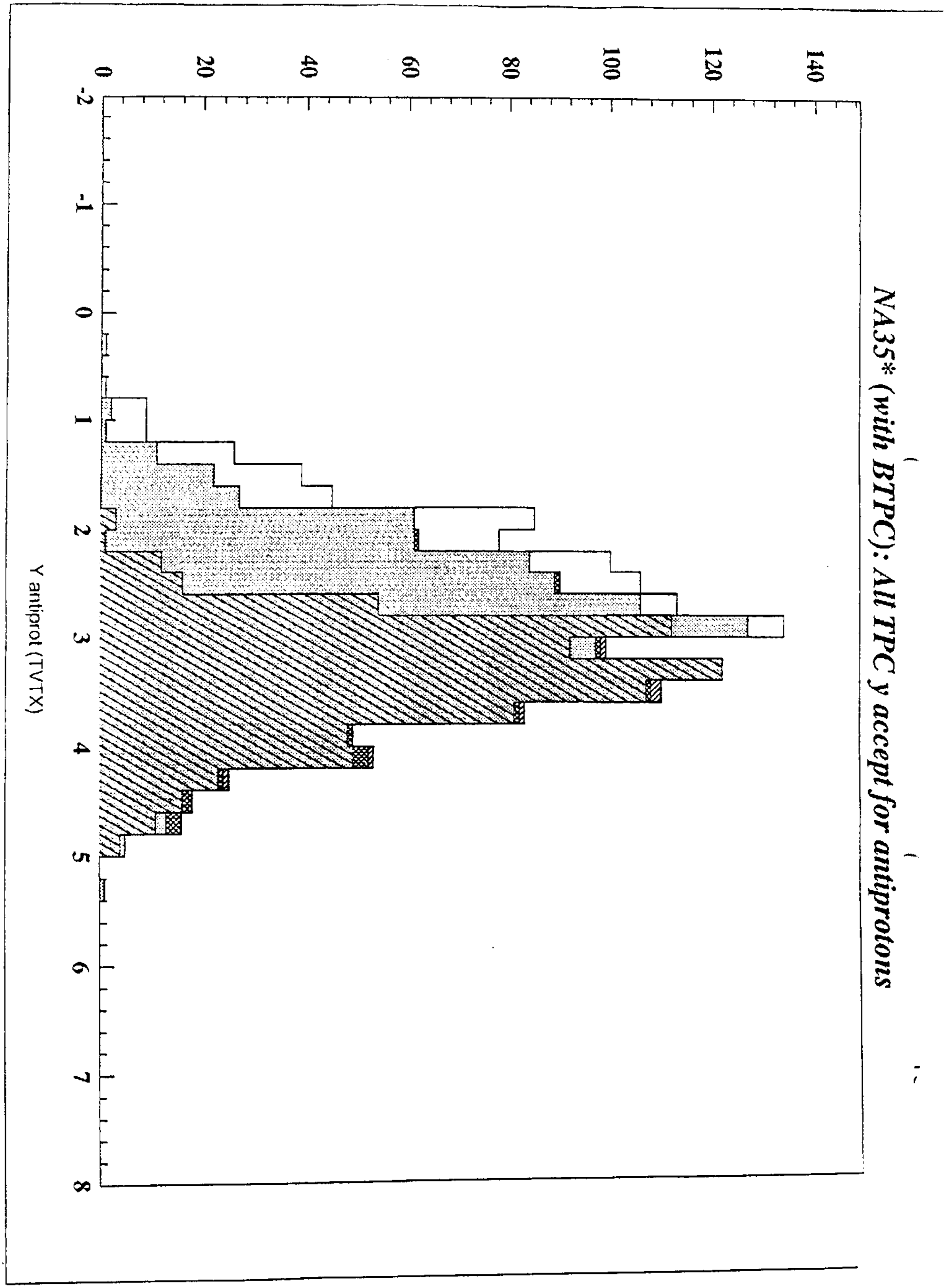


Fig. 6: Acceptance domains in y and p_T for negative pions in the Main TPC (a), Side TPC (b), and VT (1) TPC (c)


NA35* (with BTPC): All TPC y accept for pi-
2250
2000
1750
1500
1250
1000
750
500
250
0
-2
-1
0
1
2
3
4
5
6
7
8
Y pi- (TVTX)



NA35* (with BTPC): All TPC y accept for protons



NA35* (with BTPC): All TPC y accept for antiprotons

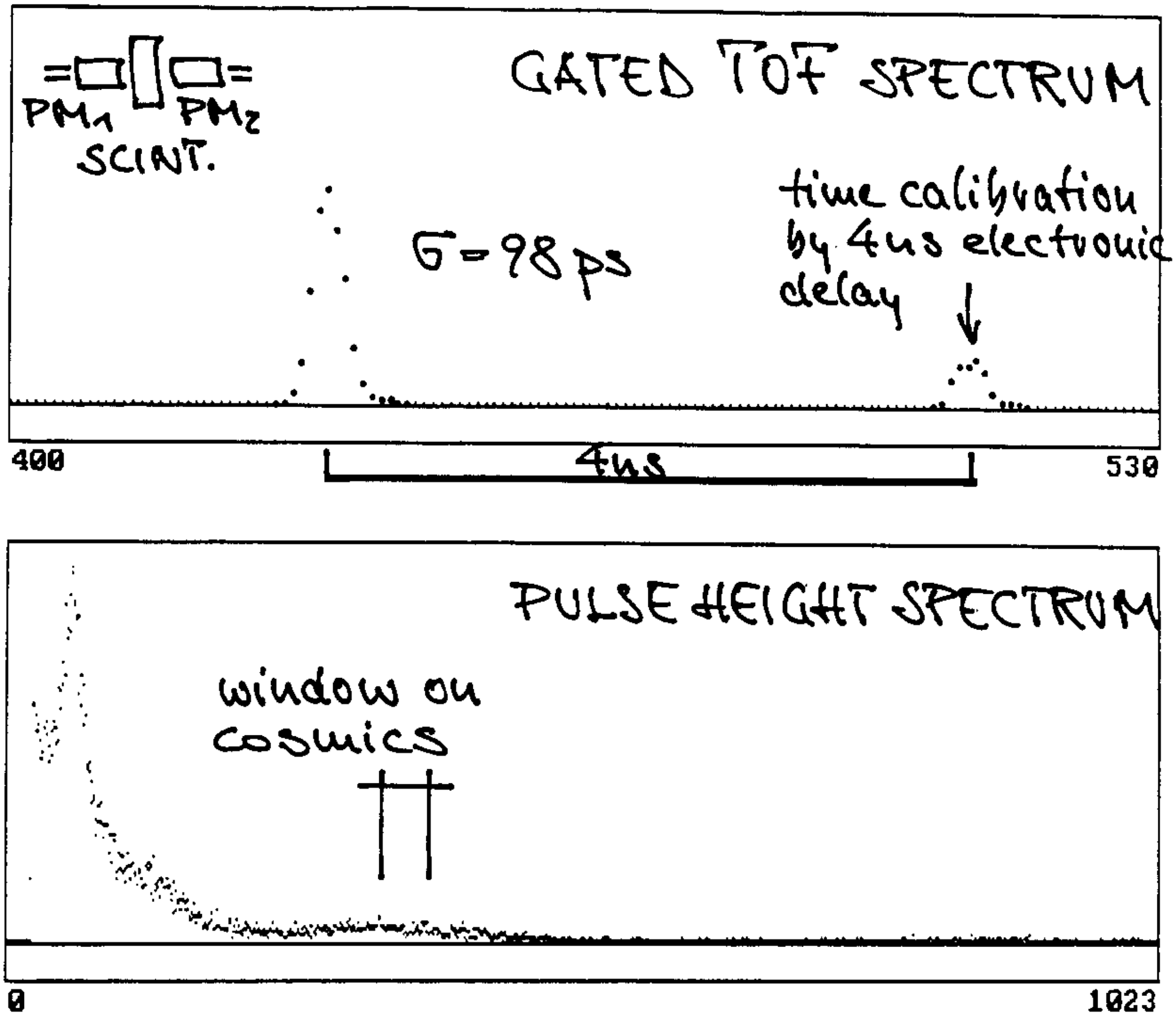


Fig. 8: Time difference spectrum obtained with two XP 2962 photomultipliers attached to a 25 x 25 x 50 mm^3 NE 104 scintillator

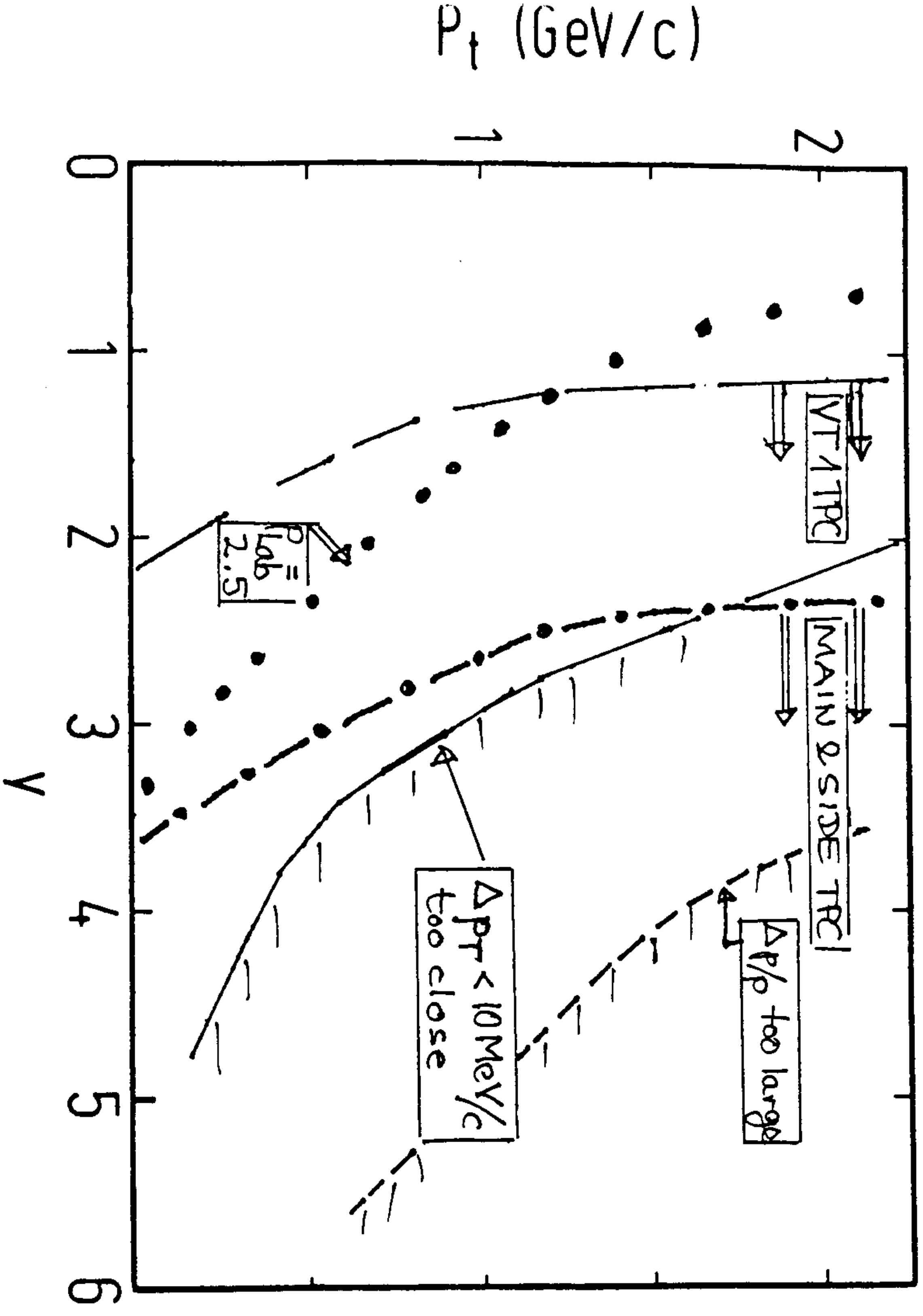


Fig. 9: Limitations to pion observation in the y and p_T plane. p_{Lab} = 2.5 GeV/c shows the lower edge of ionization identification, but in our layout pion identification occurs only in the Main and Side TPC acceptance, whereas tracking is done everywhere above the VT 1 TPC boundary line. Two track separation may limit pion pair measurement above the $\Delta p_T < 10$ MeV "too close"-line. The momentum resolution limit occurs at higher rapidity